

EVALUATION OF REPAIRS TO THE FINAL CLAY COVER SYSTEM AT THE McFARLAND-DELANO SANITARY LANDFILL, DELANO, CALIFORNIA, USA

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SUMMARY: In 2004, the existing final closure cover system for the McFarland-Delano Sanitary Landfill, located near Bakersfield, California, was found to have large cracks that ranged from 2.5 to 7.5 cm in width and penetrated the entire depth of the final cover to the top of existing waste. The cracks provided a potential conduit for precipitation to enter the waste mass and also a concentrated location for the release of landfill gas. Initially, an expensive repair procedure was employed to repair the system. In order to find a more effective and less costly repair procedure for the cover system, a full-scale alternative field test repair program was implemented. Large scale *in situ* hydraulic conductivity tests were performed on both the intact clay barrier layer and the repaired clay barrier to determine if any change to the water flow rate was identified with the alternative repair procedure. The alternative repair procedure included using a small trenching machine to open the existing cracks to a width of 10 to 15 cm down to the trash surface. A bentonite grout was then placed in the enlarged cracks. The testing program indicated that the repaired portions of the cover had the same properties as the undamaged portions of the cover and would provide a suitable means of cover repair.

1. INTRODUCTION

The McFarland-Delano Sanitary Landfill is owned and operated by the County of Kern Solid Waste Management Department and is located near the City of Bakersfield in Southern California. The unlined landfill reached capacity in the 1990's and was closed in accordance with the State of California regulations for unlined waste management facilities (California Code of Regulations, Title 27). The prescriptive cover system design per the regulations consists of the following (from bottom to top): 60 cm of compacted foundation layer soil over the refuse, a 30 cm barrier layer composed of clay with a hydraulic conductivity equal to the conductivity of the underlying native materials or less than or equal to 1×10^{-6} cm/sec (whichever is lower), overlain by a 30 cm vegetative/protective layer. The landfill cover was constructed in accordance with approved design documents and the final closure was approved by the regulatory agency.

In 2004, large cracks were observed in the final cover system at the McFarland-Delano Sanitary Landfill. These cracks ranged from 2.5 to 7.5 cm in width and penetrated the entire depth of the final cover to the top of existing waste. The cracks provided a potential conduit for

precipitation to enter the waste mass and also a concentrated location for the release of landfill gas. Based on observations of the cracks, they appeared to have been created from settlement of the refuse over time. The initial repair procedure implemented by the County of Kern was to remove the cracks by over-excavating a trench 1.5 m wide and backfilling the trench with compacted clay material from a nearby stockpile. This procedure was very expensive and the heavy equipment utilized had the potential to create additional settlement and cracking of the cover system. In order to find a more cost effective solution that would satisfy the requirements of the permit documents and regulatory agency, the County of Kern tasked their engineer to find an alternative to the existing repair procedure.

2. SCOPE OF WORK

As described in the introduction, the McFarland-Delano Sanitary Landfill was closed with a prescriptive cover that included a clay barrier layer with a required hydraulic conductivity of less than 1×10^{-6} cm/sec. Over time, settlement of the waste and drying out of the clay due to the arid conditions (the McFarland-Delano Sanitary Landfill has an annual precipitation of less than 30 cm) caused cracking of the barrier layer. The current state of the practice for the closure of unlined landfills in arid conditions is to install an alternative evapotranspirative (ET) cover due to the above problems with clay liners (Benson et al 2007). However, given that the McFarland-Delano Sanitary Landfill was closed prior to ET covers being utilized, the problems with the compacted clay barrier layer needed to be addressed. Since the excavation of the cracks with a large excavator and backfilling with clay was very expensive and could cause additional cracking due to the weight of the excavator, another alternative solution was proposed.

The proposed alternative solution was to use a small trenching machine (trench width 10 - 15 cm) to excavate the cracks down to waste. A bentonite slurry would then be prepared and placed in the trench from the waste to the top of the clay barrier layer. This procedure would be significantly cheaper than the original repair technique since no heavy equipment was necessary and it also would not create additional cracking of the clay. In order for the new procedures to be accepted by the regulatory agency, a field testing program was implemented to prove the techniques. In addition to proving the alternative repair procedures, the regulators also requested that testing be done on the in-place clay barrier layer that was not cracked to determine if it was desiccating or otherwise losing its overall effectiveness.

To satisfy the concerns of the regulatory agency, a field and laboratory testing program was conducted at the McFarland-Delano Sanitary Landfill. The field work involved full-scale repair and testing of the existing cracks and field testing of the non-cracked in-place clay barrier layer. In addition, laboratory testing was conducted on an existing clay stockpile to further evaluate the materials.

3. FIELD AND LABORATORY TESTING PROGRAM

Field hydraulic conductivity testing of the clay barrier layer was conducted using a sealed single ring infiltrometer (SSRI). Laboratory testing of the clay barrier layer stockpile material was conducted using a flexible wall triaxial test cell in accordance with ASTM D-5084. Each of the above testing methods along with the field and laboratory procedures conducted on the clay barrier layer is described below.

3.1 Testing Apparatus

3.1.1 Sealed Single Ring Infiltrometer (SSRI)

The SSRI test apparatus used consisted of a 0.63 cm thick steel ring nominally 30 cm in diameter by 36 cm high. A top or “seal” made of 0.95 cm thick polycarbonate plastic is clamped to the top of the ring using C-clamps. A rubber O-ring then creates an airtight seal between the steel and the polycarbonate top. A center valve in the top is connected by flexible plastic tubing to a burette mounted on a post next to the ring. The post is driven into the clay barrier layer next to the SSRI apparatus and the burette is set at a height of 1.5 to 1.8 meters above the clay barrier surface. The burette is marked in increments to measure outflow during the test. The SSRI apparatus, flexible tubing, and burette are insulated with separate sheltering devices to maintain a relatively constant temperature of the water over the test period. The SSRI equipment and installation is shown in Figure 1.

Typically, the ring is hydraulically pressed into the soil about 10 to 15 cm to provide a tight seal along the soil and steel ring interface. The ring can also be set in the clay by the trenching and grouting.

The setup time, date, and initial temperature of the water are recorded once the ring and burette have been filled with water to begin saturation of the test area. Any air pockets within the apparatus, which may introduce errors in the infiltration readings, are removed through ports in the polycarbonate top and burette.

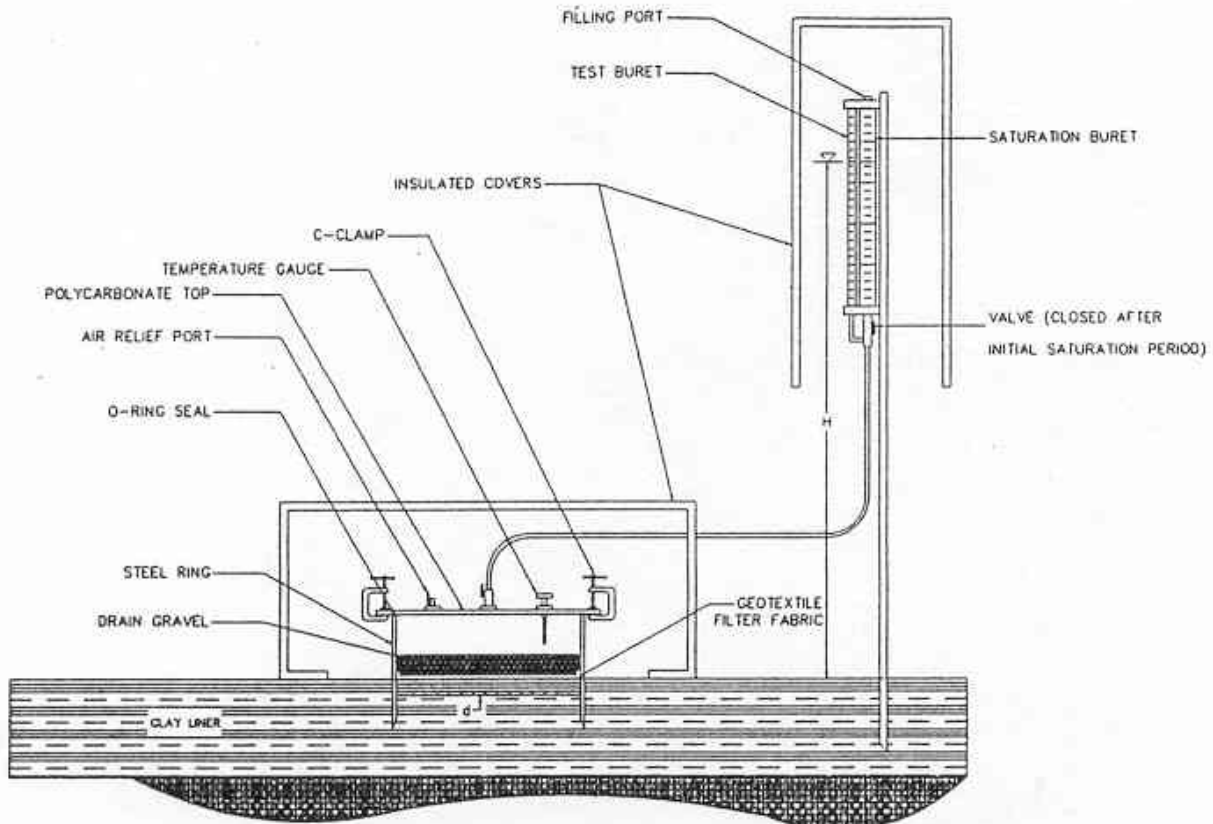


Figure 1. SSRI Set-up and Installation (after Purdy et al 2006)

The area is typically allowed to saturate for 16 to 24 hours to minimize effects of unsaturated flow and swelling of the clays. After this initial saturation period, timed infiltration measurements are recorded by monitoring the water level drop within the burette. The water temperature is also monitored to ensure that there is little or no variation over the evaluation period.

The infiltration rate, I , is then calculated as follows:

$$I = \frac{Q}{A_c \times t}$$

Where:

Q = (initial burette reading - final burette reading) $\times A_r$

A_r = area of the burette (cm²)

A_c = area of the permeameter cylinder (steel ring)

t = time between readings (seconds)

Timed readings are continued until the infiltration rate stabilizes. Once the infiltration rate stabilizes, the test is complete. The final temperature is noted, the cover removed, and the water drained from the steel ring. The depth of the wetted front in the single ring is then measured. This distance, d (cm), is then used for calculation of the hydraulic gradient, i .

The hydraulic gradient is calculated using the following equation:

$$i = (\text{total height [H] of water in the burette at time zero} + d)/d$$

The hydraulic conductivity of the clay barrier layer is then determined by dividing the infiltration by the hydraulic gradient. The effect of temperature on the infiltration of the water is obtained by multiplying the hydraulic conductivity by a temperature-viscosity correction factor to determine the final hydraulic conductivity.

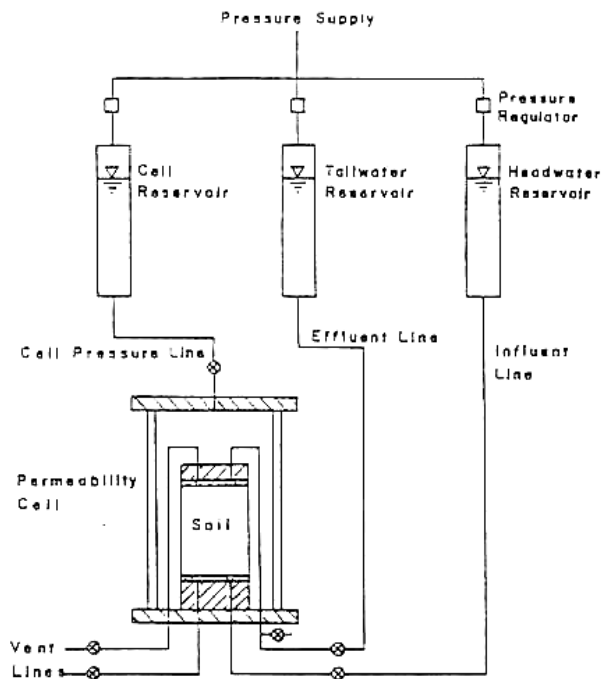


Figure 2. Triaxial Permeameter Cell (ASTM D-5084)

3.1.2 Laboratory Hydraulic Conductivity Testing

ASTM D-5084 is the standard test method currently used by the industry for determination of laboratory hydraulic conductivity. This test method operates under falling head rising tailwater test conditions using flexible wall triaxial test cells. Tests are performed on soil samples placed in a flexible membrane. Porous stones and filter paper are placed against the ends of the samples to distribute the permeant (usually de-aired water) across the entire end-area of the sample and also minimize the washing out of soils from the sample during testing. The configuration of the triaxial permeameter and soil test specimen is shown in Figure 2.

Once the sample has been prepared in the test cell, the cell is filled with water and the specimen is saturated by applying pressures to both ends of the sample (back pressuring) to force water into the sample, which expedites the saturation and testing process. For soils with expected hydraulic conductivities of less than 1×10^{-6} cm/sec, the inlet pressure of the triaxial cell is typically set at 434 kilo Pascals (kPa) and 414 kPa at the outlet, which creates a hydraulic gradient of approximately 30 across a sample 7.6 centimeters (cm) in length. The cell pressure is set at a constant pressure of 21 to 69 kPa greater than the inlet pressure. Higher cell pressures are often utilized to determine the effects of overburden consolidation on the soil liner in question, but this is not necessary for cover systems. Once testing has been initiated, saturation is confirmed when the change in the height of water in the inlet burette equals the change in the height of water in the outlet burette. Readings are performed until the calculated hydraulic conductivity has reached a relatively steady-state condition.

3.2 Field Testing Program

The field testing was performed between June 1 and June 3, 2004 at the McFarland-Delano Sanitary Landfill. Existing cracks were identified in the cover system. The cracks were labeled with a number associated with the quantity of repairs already being conducted using the original repair method on the cover and carried over for identification during the alternative repair field testing procedures. Crack numbers 33 and 34 were selected for alternative repair testing and were located near the westerly swale at the south and north ends of the site, respectively. A total of three tests were performed, SSRI #1, #2, and #3. Tests SSRI #1 and #2 were performed over crack numbers 33 and 34, respectively, where the alternative grout was used to repair the cracks. These tests would model the hydraulic conductivity of the clay barrier layer after the alternative repairs were conducted. Test SSRI #3 was performed near crack number 34 in the clay barrier layer where there was no evidence of cracking. The purpose of SSRI #3 was to determine the existing hydraulic conductivity of the clay barrier layer that had not cracked. This would model the effects of drying on the existing in-place clay barrier layer that did not crack due to waste settlement.

Preparation for the SSRI testing was accomplished by removing the existing protective/vegetative cover soil over an area approximately 3 m by 3 m wide over an existing crack until the clay barrier layer was encountered. The existing crack was then widened approximately 2.5 cm to a minimum depth of 30 cm and a minimum length of 60 cm. Loose soil was removed from the crack prior to filling it with grout. Bentonite grout was then mixed into a slurry and placed into the crack until it was entirely filled.

The SSRI steel ring was placed over each of the grout filled cracks and existing non-cracked barrier layer and pushed into the ground approximately 20 cm using the excavator bucket. During this activity, minor cracks developed from fracturing of the dry soil as the ring was pushed in. These cracks were repaired by filling them with a small amount of grout but did not impact the testing. Water was then placed within the ring and allowed to stand with the lid on overnight to begin the saturation period. The following morning, air was purged from the lid, a seal created, and the attached burette filled with water. Infiltration rates were observed during regular timed intervals, while the water temperature was monitored and recorded.

After each test was completed, the water from within the ring was removed and excavations were made by hand to determine the depth of the wetted front, or saturated zone. After calculating the infiltration and hydraulic gradient using the equations presented in Section 3.1.1 above, the hydraulic conductivity of each of the tests was determined by dividing the infiltration, *I*, by the hydraulic gradient, *i*. The resulting hydraulic conductivities of the SSRI test are provided in Table 1.

Table 1 – SSRI Hydraulic Conductivity (Permeability) Summary

Test Number	Permeability (cm/sec)	Description
SSRI #1 (Crack #33)	3.4×10^{-7}	with grout
SSRI #2 (Crack #34)	1.9×10^{-7}	with grout
SSRI #3 (Adjacent to Crack #34)	3.0×10^{-7}	<i>in situ</i> (no grout)

3.3 Laboratory Testing Program

An existing clay stockpile is located adjacent to the McFarland-Delano Sanitary Landfill. This stockpile was utilized to construct the original clay barrier layer and was also used to backfill the excavated cracks in the barrier layer in the initial repair procedure. While the field testing of the *in situ* alternative repair cracks determined that the repaired barrier layer utilizing grout had a hydraulic conductivity equivalent to the non-cracked barrier layer, the regulatory agency requested that any overall reduction in barrier layer hydraulic conductivity be determined.

In order to evaluate any potential reduction in hydraulic conductivity of the non-cracked barrier layer over time, samples of the clay from the on-site stockpile were delivered to a soils testing laboratory and remolded at similar moisture content and compaction as the original clay barrier layer. To determine the optimum moisture and maximum density, the sample of stockpile material was tested in accordance with ASTM D-1557 (Modified Proctor). After the moisture-density relationship was determined, two samples were remolded at the same criteria as the production clay barrier layer and then tested for hydraulic conductivity in accordance with ASTM D-5084.

3.3.1 Moisture Density Relationship Testing

The moisture-density relationship determination for the stockpiled clay material was performed in accordance with ASTM D-1557 (Modified Proctor). The maximum laboratory dry density and optimum moisture content criteria obtained from this sample was used to prepare the remolded hydraulic conductivity samples. Based on this testing, the maximum laboratory dry density of the clay stockpile material is 1.97 gm per cubic cm and the optimum moisture content is 11.8 percent.

3.3.2 Hydraulic Conductivity Testing

The hydraulic conductivity was determined for the clay stockpile material in accordance with ASTM D-5084. Two samples were remolded to approximately 90 percent of the maximum dry density having a moisture content of +2 percent over optimum as required for the placement of the production clay barrier layer. A summary of the hydraulic conductivity tests is shown in Table 2.

Table 2 –Laboratory Hydraulic Conductivity (Permeability) Summary

Test Number	Permeability (cm/sec)
1205A	3.7×10^{-7}
1205B	1.2×10^{-7}

4. RESULTS AND DISCUSSION

The results of the SSRI testing conducted at the McFarland-Delano Sanitary Landfill for the County of Kern show that the hydraulic conductivity of the alternative grout-repaired cracks are similar to the clay barrier layer without any cracks. The average hydraulic conductivity of the two grout-repaired cracks was determined to be 2.7×10^{-7} cm/sec. The hydraulic conductivity of the *in situ* non-cracked clay barrier layer was determined to be 3.0×10^{-7} cm/sec. The hydraulic conductivity testing of the non-cracked clay barrier layer also demonstrated that the cover still satisfied the specified regulatory requirements of less than 1×10^{-6} cm/sec even after going through several years of operation in arid conditions.

The hydraulic conductivity tests performed in the soils laboratory on the remolded material obtained from the clay borrow stockpile provided an excellent correlation between the in-place clay cover without cracks (or cracks repaired with grout). The results also show that there is an excellent correlation between the field SSRI and the laboratory triaxial tests performed on the McFarland Delano Sanitary Landfill barrier layer clay. These results are similar to the studies reported by Purdy et al (2006) discussing the correlation that can be obtained between field and laboratory hydraulic conductivity testing. It should be re-emphasized that the correlation between the in-place cover layer hydraulic conductivity and the remolded clay stockpile material hydraulic conductivity indicates that the existing non-cracked clay barrier layer is still performing to the design standards that were met during initial placement.

5. CONCLUSIONS

Based on the hydraulic conductivity results obtained from the above field and laboratory testing program, using a bentonite grout to repair the cracks in the final clay barrier layer at the McFarland Delano Sanitary Landfill is a cost effective solution and is recommended for future repairs at the site. Not only does this procedure cost significantly less than the original method of excavating a wide trench over the cracks and backfilling with compacted clay, it also limits contact with any heavy equipment that could increase the overall cracking of the cover. Using a small trencher, cracks can be excavated 10 to 15 cm wide to the top of waste, filled with bentonite grout to approximately 30 cm from the top of ground surface, and covered with a vegetative/protective layer to finished grade with minimal compaction. Although the alternative field testing repair method utilized hydrated bentonite grout to perform the SSRI testing, it is recommended that unhydrated grout be placed in the cracks for the repairs. This would reduce the potential for shrinkage of the grout and also be less susceptible to any further settlement of the clay cover.

While clay barrier layers are no longer recommended as a cover layer over municipal waste landfills due to their cracking as the refuse settles, the close correlation between the non-cracked *in situ* clay barrier layer and the remolded clay stockpile material indicated that the properties of the in-place clay were maintained even after several years in an arid environment. It is suspected that the overlying 30 cm of vegetative/protective soil insulated the clay barrier layer and reduced any effects from desiccation.

Based on the performance of the non-cracked clay barrier layer, it can be concluded that the cover system at the McFarland Delano Sanitary Landfill can operate as designed with periodic

maintenance of any cracks that develop due to settlement of the waste. Quarterly inspections of the cover surface will provide sufficient observations of the cover performance and allow for repairs of cracks to be completed on a timely basis.

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